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COMPARISON OF VARIOUS CHEMICAL QUICK TESTS ON DIFFERENT SOILS

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CONTENTS

	Page
Introduction	1
Historical sketch	2
Nature of quick soil tests in current use	6
Extracting solutions	7
Chemical reactions involved in tests	8
Methods of expressing results	8
Extent of present usage	8
Results by different outfits and procedures on different soils	9
Soils used	9
Soil acidity	10
Lime requirement	12
Extraction and determination of phosphorus and potassium	13
Availability of soil nitrogen	16
Relation of chemical data to field fertilizer practice	16
Other soil constituents	19
General relations	19
Summary	19
Literature cited	20

INTRODUCTION

For many years agriculturists have been in search of chemical means by which to determine the available portion of phosphorus, potassium, and sometimes other elements present in a soil. By this is meant the part capable of serving the immediate and progressive needs of a plant as distinguished from the whole or potential supply. Nearly a century of intermittent efforts had until recently produced a very pessimistic attitude on the part of most chemists and agriculturists regarding the general practicability of any tests of this kind.

It is a relatively simple matter to make an inventory of the total plant-nutrient resources of a soil by means of an ultimate chemical analysis, but it is well known that no close relationship has been found between the total quantities of the various soil constituents and the supply available to plants. Furthermore, the amount of the various nutrient elements removed from a soil by water, by a plant, or by any one of various extracting solutions bears a very indefinite relationship to the whole quantity of a particular element present.

The quantity of the various elements ordinarily added to a soil in a fertilizer in any one season is so small as compared with the total normal supply in the soil that a chemical analysis for total constituents would ordinarily fail to detect the addition of commercial fertilizer. The soil from a 1-acre field to a depth of 1 foot weighs approximately 4,000,000 pounds. Published data on six widely diversified surface soils selected at random show an average of 0.14 percent nitrogen, 0.19 percent phosphoric acid, and 1.64 percent potash. If as much as 1,000 pounds of 5–8–7 fertilizer were added per acre it would increase the total supply of nitrogen from 5,600 to 5,650 pounds, the phosphoric acid from 7,600 to 7,680 pounds, and the potash from 65,600 to 65,670 pounds per acre. Such differences would scarcely vary the percentages of constituents as determined in the second place after the decimal, and are obviously too small to be estimated accurately by means of the methods ordinarily used in complete soil analysis. Although such slight additions of fertilizer constituents may greatly influence plant growth, they must be detected chemically by their partial solution in selected solvents rather than by their determination as a part of the whole.

Because of the disappointing results from most of the numerous and varied efforts directed at precisely evaluating availability of soil constituents by chemical means, many agriculturists have become willing to use approximate tests which are known to be far from perfect. They require only that such tests must appear to aid in a more intelligent selection of soils for particular purposes and to make probable a more economical use of fertilizer than if no tests were used.

During recent months this Bureau has received a large number of requests for recommendations of quick-test outfits for diagnosing the fertility of a soil and judging the probable response of crop growth when fertilizers are added. The so-called quick tests, known also by various terms such as "test set" or "soil-testing outfit", are those which can be made in the field by persons without high scientific training and with a minimum of laboratory facilities. These sets are accompanied by directions for their operation and for interpretation of the results. Frequent requests are received for an opinion regarding the reliability of outfits on the market. Consequently it has been considered desirable to obtain some systematic information on the value of the various commercial outfits for rapid soil analysis now being sold throughout the country. It is particularly desirable to know how results obtained by the use of these various outfits compare with one another, and how they are correlated with plant growth on different soils under various conditions. The desired answer is not now at hand, but certain of these quick-test outfits have been used, and the results should be of value for comparative purposes. It is not expected that satisfactory results will be obtained with any single test for a particular element on all kinds of soil for all kinds of crops. It is hoped, however, that subsequent developments may make possible more intelligent application of various procedures to particular kinds of soil and thereby add to the practical value of various testing procedures, commercial and otherwise, now being used.

Comparative data from a group of widely differing soils should be of value to prospective users of these quick-test outfits. Some data of this kind have been obtained and are given in this report, together with a discussion of some of the experiences of others.

Preliminary investigations only are discussed in this publication. It is realized that further studies must be made, especially of diversified soils growing crops in response to various fertilizer treatments.

HISTORICAL SKETCH

In 1845 Daubeny (*9*)[1] suggested the terms "active" and "dormant" to express the more and less soluble constituents of a soil, respectively. He proposed the use of carbonic acid to distinguish between the two classes of materials. However, presumably on account of difficulties with the analytical procedures in use at that time, the subject appears to have been forgotten until it was later revived by H. von Liebig and continued by a host of subsequent investigators. The literature is so extensive that any comprehensive review would be far beyond the scope of this publication. Only a few of the more important developments can be mentioned here.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 20.

One of the early investigations dealing with the availability of phosphorus and potassium was published by H. von Liebig (*24*) in a series of papers giving somewhat fragmentary data. The soil samples came from the Rothamsted Experiment Station plots, and their crop and fertilizer histories had been known for nearly 30 years. Dilute hydrochloric, nitric, and acetic acids were used. Varying quantities of phosphorus and potassium were removed by the different acids, and these constituents varied with the different manurial treatments received by the soils. The chief interest in these data lies in the fact that it marks the beginning of continuously active interest in the problem of determining the availability of plant nutrients by chemical means.

The first widely recognized work of this kind appearing in the English language was that of Dyer (*11*), published in 1894. In this work, done at the Rothamsted Experiment Station, Dyer made a study of the acidity of the sap from various plants. In accordance with the information from that study, he chose a 1-percent solution of citric acid as the solvent the effect of which he thought would most nearly approximate the action of plant roots in contact with the soil. His experiments showed a fair agreement between laboratory data and crop yields on plots the records of which dated back at least 20 years. Dyer's method with certain modifications is used by some even at the present time, in spite of analytical inconvenience and the inapplicability of the procedure to most calcareous soils (*8*).

Many attempts have been made to substitute some other solvent for citric acid. These solvents include, in particular, nitric, sulphuric, hydrochloric, and acetic acids in varying concentrations, both with and without the addition of salts.

For a period of years many analyses were made of the constituents dissolved from soil by long digestion with hydrochloric acid (specific gravity 1.115). In fact, for several years this procedure was recognized as an official method by the Association of Official Agricultural Chemists (*1*). The method was never intended to indicate the quantities of plant nutrients available in a single season. In fact, it was looked upon as a measure of the portion of various elements which might become available over a longer period, perhaps 20 to 100 years. The results show, as a rule, much larger quantities of the various constituents than are dissolved by the weak or dilute acids frequently used. The amounts of the various elements dissolved by the strong acid digestion lie somewhere between the quantities taken up by crops grown in a single season and the total constituents present in the soil as shown by fusion analysis. Because of the midway character of the results and the very indefinite interpretations possible in terms of crop response, this method, once popular, is now but little used.

Base and anion exchange in soils, in which there is widespread current interest, is intimately related to the availability of soil nutrients. Numerous studies of this kind have had for their objective a determination of the relationship between various nutrients dissolved from soil by neutral salts and the adequacy of the available supply of these for plant growth. The consensus of opinion appears to be that the quantity of calcium, magnesium, potassium, and other bases replaced by the ammonium ion from neutral ammonium chloride or ammonium acetate is about as definitely related to the available supply as the quantity determined by any laboratory procedure in use. The analytical procedures involved of course require considerable time, and the results are not capable of very definite interpretation. Furthermore, the results of Proebsting (*36*) and others have shown that in certain soils at least some of the nonexchangeable potassium may be readily available to plants. Twentieth normal hydrochloric acid, which is frequently used as a base-exchange extracting solution, usually extracts approximately the same amount of cations as does a normal solution of a neutral salt. More concentrated solutions of strong acids of course dissolve somewhat greater quantities of soil constituents. Solutions of nitric or hydrochloric acid as strong as 0.1 or 0.2 normal are frequently used in base-exchange studies, although there appears to be little reason to regard results with these more concentrated acid solutions as of greater diagnostic value than those obtained with solutions of salts or with less concentrated acids.

Electrodialysis is another procedure frequently used for preparing solutions of soil nutrients. By this operation the phosphates together with other anions are collected in the anode chamber, and the calcium, magnesium, potassium, and other cations are collected in the cathode chamber. Appropriate chemical analyses are then made. As electrodialysis proceeds, the soils become acid to varying degrees, depending on the fundamental character of the soil. The quantities of various cations removed are usually about the same as when neutral salts are used for base exchange. The phosphates removed were found by Humfeld (*20*) to be fairly well correlated with crop responses except where soils had received rock-phosphate treatment, in which case the results by electrodialysis were higher than would be expected from crop response. Acid solutions have also frequently been found to dissolve unavailable phosphate from soils previously treated with certain applications, which additions have been converted to a low condition of availability.[2]

Much work has been done on the relations of plant growth to soil constituents dissolved by pure water. These solutions have been obtained in a variety of ways, including simple shaking with water followed by filtration. The diffusion of dissolved soil constituents through collodion bags was recommended by Pierre and Parker (*34*). The extraction of soil solutions by various liquid-displacement methods has frequently been suggested (*6*, *25*, *26*). In spite of the numerous investigations of the relationship between soil fertility and the quantities of water-soluble constituents of the soil, such relationship as may exist is still very uncertain.

During the last few years great interest has been shown throughout the world in the development and use of laboratory means for diagnosing the state of fertility of soils and the needs of soils for fertilizers. The development of methods is epitomized in table 1, where some of the more prominent procedures are listed. Some of the more recent of these methods have been adapted to what are commonly known as quick tests. The equipment for these tests is in compact and portable form.

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[2] MORGAN, M. F. THE VARIANCE OF METHODS OF TESTING FOR PHOSPHORUS ON SOILS PREVIOUSLY TREATED WITH DIFFERENT PHOSPHATE FERTILIZERS. Amer. Soc. Agron. Proc. Ann. Meeting: 45–51. 1935. [Mimeographed.]

TABLE 1.—*Methods proposed for the determination of available soil constituents, particularly phosphorus and potassium, and their relation to fertilizer requirements*

Author and year of investigation	Solvent used	Remarks
Daubeny, 1845 (*9*)	Carbonic acid	
von Liebig, 1872 (*24*)	Dilute acetic acid and HCl	K and P are both considered.
Dugast, 1883 (*10*)	Aqua regia, ammonium citrate, acetic acid, carbonic acid, and water.	Comparison of phosphorus extracted by these various solvents.
Lechartier, 1884 (*23*)	2 percent ammonium oxalate	For P only.
Eggertz and Nilson, 1889 (*12*)	2 percent HCl and 4 percent HCl.	Soil is rendered sterile to certain crops by extraction with 2 percent HCl and washing with water.
Dyer, 1894 (*11*)	1 percent citric acid	Soils with less than 0.01 percent soluble P_2O_5 probably need phosphatic fertilization.
Peter and Averitt, 1906 (*33*)	0.2 normal HNO_3	For P only.
Association of Official Agricultural Chemists, 1907 (*1*).	0.2 normal HCl	Do.
Fraps, 1909 (*13*)	0.2 normal HNO_3	Do.
Neubauer and Schneider, 1923 (*31*).	Analysis of seedlings grown in soil.	A single test may be for either P or K.
Das, 1926 (*8*)	Alkaline carbonate solutions	For calcareous soils K_2CO_3 and Na_2CO_3 are better than $(NH_4)CO_3$.
Hoffer, 1926 (*19*)		Various reagents used on cornstalks indicate deficiencies of nitrogen, phosphorus, and potassium.
Oden, 1927 (*32*)	Electrodialysis	Plants obtain their nutrients from exchangeable ions only.
Humfeld, 1928 (*20*)	do	Both anode and cathode dialysates may be analyzed.
Spurway, 1929 (*37*)	Water solution	For phosphorus only.
Bray, 1929 (*2*)	Ammonium molybdate and HCl	Test is made in the solution with soil present.
Truog, 1930 (*44*)	0.002 normal $H_2SO_4+(NH_4)_2SO_4$ at pH 3.0.	For phosphorus only.
Thornton, 1931 (*41*)		Analysis of seedlings.
Morgan, 1932 (*28*)	Various extracting solutions	Various micromethods are described.
McGeorge, 1932 (*26*)	Electrodialysis	Recommended for P in calcareous soils.
Bray, 1932 (*3*)	Sodium acetate and HNO_3 approximate pH 4.4.	For K only.
Spurway, 1933 (*38*)	Very dilute acetic acid	All constituents are tested.
Harper, 1933 (*17*)	Electrodialysis	
Murphy, 1934 (*30*)	Conventional base-exchange procedure.	Oklahoma soils with less than about 60 p. p. m. of replaceable K respond to K fertilization.
Morgan, 1935 (*29*)	Sodium acetate	All constituents are included.

Anyone interested in quick soil tests naturally would like to know how accurately these tests may serve as an index of plant growth on the soils tested. Many statements indicating correlation of tests with crop growth in general terms have been published. A few writers have attempted more definite mathematical statements, but for the most part these are not very convincing. The difficulty of satisfactory correlation is due in part to the considerations involved. Agronomists are interested not only in whether a certain fertilizer does or does not produce a crop increase but also in whether the increase, if any, is economically advantageous when all factors are considered.

Extensive experiments by Fraps (*13*) led to the conclusion that Texas soils from which 0.2 normal nitric acid extracted 20 to 100 parts per million of phosphoric acid usually did not contain enough phosphorus for the growth of corn. Studies of active soil potash extracted by the same solvent (*14*) indicated that no relation could be traced between the weight of a crop and the active potash in the soil.

Harper (*16*) has summarized the results of several thousand available phosphorus determinations made on soils from all parts of Oklahoma. The phosphorus was extracted from the soil by means of a 0.2 normal solution of sulphuric acid. The determinations were then made in a conventional manner. Generalizations from the results were summarized in a table entitled "Relation between easily soluble phosphorus in soil and response of crops to phosphorus fertilization." The easily soluble phosphorus in pounds per acre, above which quantity phosphorus fertilization is not usually profitable, varied with the different crops as follows: Alfalfa, 40 to 60 pounds; oats, 30 to 40 pounds; corn, 20 to 30 pounds; and grain sorghums, 15 to 20 pounds per acre.

Goodwin (*15*) studied various modifications of the electrodialysis process as a means of determining the availability of soil phosphorus in calcareous soils of Colorado. He arbitrarily selected 0.8 mg of phosphorus removed from 5 g of soil by 1,000 coulombs of electricity as the dividing line between sufficiency and deficiency of available phosphates. The results thus obtained agreed with the field response in 68.9 percent of the soils studied. On the same soils, results by a potassium carbonate extraction method agreed in 86.7 percent of the cases. The results for water-soluble phosphorus were the most reliable index of phosphate sufficiency, agreeing with field results in 91.1 percent of the 45 cases studied. Positive and negative responses only were recorded, with no indication of the extent of crop increase as a result of phosphate application. In spite of the good showing made by the water-soluble phosphate test in this instance, the consensus of opinion from tests made on soils in different regions seems to be that its usefulness is more limited than results by certain acid or salt-extraction methods.

Many general statements have been made by investigators concerning the correlation of crop results with those of the popular quick tests, but definite data appear to be few or lacking.

NATURE OF QUICK SOIL TESTS IN CURRENT USE

The rapid chemical soil tests used in the United States during the last few years vary widely. Some are quick in the sense that they require only a few minutes' time; others are partly biological in that chemical tests are made upon plants grown for stated periods of time in the soils to be tested. Strictly speaking, those involving plant growth are not quick tests, although they are quicker than methods involving field-crop yields. The Neubauer (*31*) method involves an actual chemical determination of a single element, either phosphorus or potassium, in the plants grown under the conditions prescribed in the test, and is considerably used. Current literature describes several applications of this method (*7*). The method of Thornton (*42*) is a quick chemical test made on the tissue of growing plants.

Most of the tests in common use, and all the test kits examined in this comparison, employ extracting solutions in some manner. Various State agricultural experiment stations have investigated quick tests as applied to the soils of their respective States. Many methods and modifications of methods have been published by these institutions. In several cases the methods published have been commercialized. In other cases the information furnished with commercial sets gives no clue as to the chemical composition of the various materials used for the tests. The company then expects to furnish refills as a part of its business. Both kinds of sets are included in the seven tested in the work reported here. Research and testing laboratories of course frequently prefer a system which allows them to make up their own reagents from stock chemicals.

The Simplex set is manufactured according to directions given by Spurway (*38*) in a bulletin of the Michigan Agricultural Experiment Station. The Urbana laboratories use essentially the directions of the Illinois Agricultural Experiment Station, and the LaMotte and Hellige outfits are stated to be based in part on the published work of the Wisconsin Agricultural Experiment Station. The Emerson outfit was developed at the Iowa Agricultural Experiment Station, but the directions for its use were not published. The Indiana outfit was developed by the Purdue Agricultural Experiment Station, and the directions were published by that institution (*43*). This set is furnished to residents of the State on essentially a cost basis. The same courtesy of purchase was extended to this Bureau. No information is given regarding the chemicals used in the Sudbury outfit.

The tests vary in acidity of the extracting solutions used and in details of operation. The ratio of soil to extracting solution used varies with the different tests as does also the time of contact. In most cases the extracting solution is filtered from the soil. Different soils of course vary widely in the rate at which liquid passes through the filter; thus the period of contact of soil with extracting solution is unavoidably varied. It would seem that the methods used in the commercial test sets accord fairly well with current usage in various State experiment stations. However, the more recent publications indicate a tendency toward the use of less acid-extracting solutions and the substitution of solutions more highly buffered with salts for the purpose of maintaining a nearly constant pH throughout extraction. Methods employed for quick tests change so rapidly that test sets purchased a few months ago may not be identical with those being marketed when this publication goes to press. Furthermore, others may be changed before this publication is ready for distribution. Experiment stations frequently publish modifications of methods, which supersede previous ones.

EXTRACTING SOLUTIONS

Some procedures employ only one extracting solution for dissolving the various constituents. The Simplex outfit, developed by Spurway (*38*) of the Michigan Agricultural Experiment Station, uses this procedure. The extracting solution used is made by adding 1 drop of acetic acid (1 part of glacial acid to 3 parts of water) to 13 cc of water. This produces a solution having a pH value of about 3.3. The procedure used by Morgan (*29*) of the Connecticut Agricultural Experiment Station employs a universal extracting solution made as follows: 100 g of sodium acetate ($NaC_2H_3O_2.3H_2O$) is dissolved in 500 cc of water, 30 cc of glacial acetic acid is added, and the whole is made up to 1 liter. This solution is buffered at pH 4.8. Hester (*18*) of Virginia uses a similar extracting solution made by adding 20 cc of glacial acetic acid and 10 g of sodium hydroxide to sufficient water to make a volume of 2 liters. This is highly buffered at pH 4.8 to 5.0. The extracting solutions used for individual constituents are numerous and varied; most of them are more acid than those noted above. Those used in this comparative study are described later, when particular constituents are considered in detail.

CHEMICAL REACTIONS INVOLVED IN TESTS

All the quick-test sets utilize some modification of the Denigès method (*45*) for determining minute quantities of phosphates. A blue color is developed when soluble soil phosphate in an acid molybdate solution is treated with a stannous salt or is stirred with metallic tin. Most of the sets determine potash by precipitating with sodium cobaltinitrite in the presence of ethyl alcohol or isopropyl alcohol, and estimating turbidity in some prescribed manner. The potash tests of the Emerson and the Sudbury outfits are conducted on a different principle. In these tests potash is determined by extraction with a colorless solution which assumes an amber to red color as the need for potash applications is indicated. In most of the quick-test outfits nitrates are apparently determined with the same reagents, that is, small quantities of the soil solution are treated with diphenylamine and concentrated sulphuric acid. The blue color developed is compared in a conventional manner with a color chart.

METHODS OF EXPRESSING RESULTS

Methods of expressing the results obtained by the various quick-test sets and testing systems are not uniform. Some express results as parts per million of a particular constituent in available form in the soil. Others interpret results directly from color standards in terms of the probable applications of a particular element needed for good crop growth. Frequently the supply of a constituent in available form is indicated only in general terms, such as high, medium, and low. In still other cases a general expression of results is further broken down into additional classes, such as very low, low, medium, high, and very high. By the exercise of some judgment on the part of the operator the various results may be interpreted as falling in the five groups just mentioned. In this report the results are interpreted as falling in these five groups. The operator is of course called upon in some cases to exercise judgment not contemplated by the makers of the set.

EXTENT OF PRESENT USAGE

Rapid soil tests in one form or another are used in most of the State experiment stations. The extent to which they are used varies widely in different localities as does also the kind of test employed. Recently R. P. Thomas of the University of Maryland made a careful survey of the use of rapid tests in the various States. He has published two reports, which very fully summarize the status of this work throughout the country in 1935[3] (*40*). Tests for acidity and lime requirement of soils have long been in use. The reports of Thomas show that the tests for pH value is now more frequently made than any other single determination. He also found that phosphorus-deficiency tests rate second in number of tests made in the United States. Two-thirds of the State experiment stations make some phosphorus tests. The test for potassium was found to be used much less, and in only a few States were separate tests made for calcium and magnesium. Tests for organic matter, nitrate nitrogen, and other constituents were made in only a few State laboratories, and the number of these tests made was small. Thomas' survey covered only those made by State experiment stations, county agents, and other public employees. No definite information is available regarding the extent of usage of the various tests by private laboratories and individual farmers. There is no doubt, however, that the number is large and appears to be increasing. Makers of some of the portable testing kits report wide usage of these outfits by individuals as well as by institutions.

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[3] THOMAS, R. P. THE USE OF RAPID SOIL TESTS IN THE UNITED STATES. Amer. Soc. Agron. Proc. Ann. Meeting: 63–72. 1935. [Mimeographed.]

RESULTS BY DIFFERENT OUTFITS AND PROCEDURES ON DIFFERENT SOILS

In view of the extensive use of quick soil tests by commercial laboratories, State experiment stations, county agents, and individual agriculturists, it is obviously desirable that the various procedures be tried on a uniform set of soils.

A few months ago a number of the test kits offered for sale by various commercial establishments were acquired. The different determinations were made with them on a group of widely diversified soils. Several of the methods proposed in scientific literature but not incorporated in any of the commercial outfits were also used on these same soils. No attempt was made to include all the processes in use; only the ones more widely used were compared. The sets used included the Simplex, Emerson, LaMotte, Sudbury, and Hellige, also the test sets manufactured by the Urbana Laboratories and the set made and used by the Indiana Agricultural Experiment Station.

The directions accompanying most of these sets emphasize the importance of obtaining a representative soil sample for testing purposes. For the most part, the instructions for obtaining the sample appear to be fairly satisfactory. The soil of a field may be nearly uniform or it may be highly variable within a distance of a few rods. It is often desirable to take several sets of samples from one field. In sampling a field it is usually best to select a representative area of a few square rods and from 5 to 10 places within this small area take small samples to about plow depth. These samples, of perhaps one-half pint each, are then mixed on a cloth or paper. Grass, manure, and rubbish are removed from the surface before the sample is taken.

SOILS USED

The soils selected for the comparative studies differed widely. They were subsamples from type profiles used in other studies. Extensive chemical and physical data obtained with them have been previously published (*4*, *27*). The soils had been air-dry for several months. In this condition they probably gave results significantly different from those that would have been obtained if they had been used fresh from the field. The use of moist soils is frequently recommended in preference to air-dry ones, although directions accompanying most of the test kits call for air-dry sieved soil samples. The samples used were from virgin soil profiles. In this respect they differ from soils frequently fertilized, which are the ones most frequently subjected to testing. However, the use of virgin samples presents certain advantages for a preliminary comparison of this kind, since extensive chemical data for the samples are available.

The Barnes silt loam is a typical Chernozem soil from South Dakota; the Carrington silt loam is from Iowa and is representative of the Prairie group. The Clinton silt loam from Wisconsin, and the Miami silt loam from Indiana are of the Gray-Brown Podzolic group. The Cecil clay loam of North Carolina and the Ruston loamy sand of Georgia are red lateritic soils. The Caribou loam is a typical Podzol from northern Maine. Only the upper horizons, where plant roots readily penetrate, were tested. Pertinent data from previous bulletins are summarized in table 2. Data on depths and horizons of the soils in subsequent tables and figures are taken from table 2.

TABLE 2.—*Quantities of various constituents present in soils*

Kind of soil and laboratory no.	Horizon	Depth	Colloid content	P_2O_5	K_2O	CaO	N	Organic matter
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cecil clay loam, 9415	A	0 -6	30.6	0.16	0.57	0.24	--------	2.44
Cecil clay loam, 9416	B_1	6 -32	55.7	.15	.47	.20	--------	.34
Ruston loamy sand, B161	A	0 -14	7.3	.07	.24	.36	0.04	1.85
Ruston loamy sand, B162	B	14 -40	37.4	.05	.29	.07	.04	.50
Miami silt loam, 10341	A_1	0 - 1½	18.1	.11	2.11	1.26	.32	7.19
Miami silt loam, 10342	A_2	2½- 9	20.2	.11	2.25	.76	.16	2.79
Miami silt loam, 10343	B	11½-23½	50.6	.14	2.16	.90	.09	.83
Caribou loam, 10541	A_2	¾- 2	12.3	.10	1.06	.38	.22	3.86
Caribou loam, 10542	B_1	2 - 4	18.3	.23	1.21	.50	.23	5.52
Barnes silt loam, 10305	A	0 - 9	26.7	.17	1.80	1.61	--------	5.98
Barnes silt loam, 10306	B_1	9 -17	25.3	.11	1.76	1.53	--------	2.36
Carrington silt loam, 10082	A_1	0 - 3	21.2	.11	1.53	.99	.29	5.57
Carrington silt loam, 10083	A_2	3 -13	22.5	.10	1.53	.96	.17	3.43
Clinton silt loam, 10362	A	0 - 8	11.2	.22	2.30	.33	.13	1.55
Clinton silt loam, 10363	B_1	8 -20	18.8	.22	2.32	1.22	.05	.59

SOIL ACIDITY

Soil-acidity determinations are made by far the most frequently of any of the quick soil tests. The degree or intensity of soil acidity (pH) alone is an important index to the soil condition in several ways, but the importance of small differences in soil acidity is no doubt often overemphasized. The pH is important because it is closely correlated with the natural distribution of many kinds of plants. Several important field crops are limited in their distribution because of the degree of acidity of soils or on account of other factors which are usually more or less correlated with acidity. Soil acidity naturally develops as the parent minerals under vegetative cover are leached with an abundant supply of water. Calcium as well as other bases is carried away in the drainage water. Acid soils are apt to be deficient in available calcium and frequently in other bases. This deficiency is often corrected, in part at least, by the addition of limestone, dolomitic limestone, or hydrated lime. Because of the general correlation usually found between soil acidity and the growth response of certain plants to addition of lime, acidity is often expressed in terms of so-called lime requirement. From the laboratory standpoint this, generally speaking, is the amount of lime which must be added to bring a soil to some arbitrary pH. From the practical or agricultural standpoint, it is the quantity of lime required for the best growth of plants insofar as lime additions have an influence. It is obvious that the hydrolysis and leaching which have taken place in the development of acid soils have frequently depleted the soil of other bases as well as calcium; hence the restoration of fertility is greatly complicated.

The acidity determination is probably the most accurate and satisfactory of any of the rapid tests in use. Varying degrees of refinement of the test are possible, ranging from a rough estimate of the tint of some indicator in contact with a soil solution to the most precise electrometric measurement. As a rule the colorimetric tests in general use are sufficiently accurate for practical purposes. Some of the tests employ various indicators taken alone; others use a mixture of indicator solutions. Sometimes the indicator is placed in contact with the soil, and sometimes it is added to a soil solution. Various kinds of comparators are then used with solutions for matching the color tint against that of a standard buffer solution, or the color may be matched against a lithographed color chart. There appears to be little question regarding the general suitability of most of the pH tests for various kinds of soil, except when the soil solution is deeply colored or when some other interfering substance may be present.

A comparison was made of five colorimetric methods and two laboratory electrometric methods using a glass electrode and a hydrogen electrode. The results given for the quick colorimetric tests are single determinations made individually by two observers without reference to the results by the electrometric procedures. The LaMotte and the Indiana outfits each use separate indicator solutions. The LaMotte set uses four indicators: Bromcresol green (pH range 3.8 to 5.4), chlorphenol red (pH 5.2 to 6.8), bromthymol blue (pH 6.0 to 7.6), and phenol red (pH 6.8 to 8.4). The Indiana test reagents consist of three indicators: Bromthymol blue, bromcresol green, and chlorphenol red. The Simplex test is made by the use of a single solution which is apparently a mixture of several indicators.

A method often used consists of shaking a soil with water in some convenient proportions, such as 1 part of soil to 2 of water, allowing it to settle for an hour or two, pouring the extract into depressions of a spot plate, and adding one of the appropriate indicators listed in the color chart published by Clark (*5*). This is for solutions in general and is widely used for approximate colorimetric hydrogen-ion work. A comparison of the results by the different methods is given in table 3.

TABLE 3.—*Acidity of various soils indicated by different procedures as determined by analysts A and B*

Kind of soil and laboratory no.	Glass electrode	Hydrogen electrode	Soiltex		Indiana		LaMotte		Hellige		Colorimetric test on spot plate
			A	B	A	B	A	B	A	B	
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Cecil, 9415	5.1	5.1	5.3	4.0	5.6	5.6	5.6	5.3	5.5	5.5	4.8
Cecil, 9416	4.5	4.5	4.0	4.0	5.2	5.3	5.2	5.0	5.2	5.0	4.6
Ruston, B161	4.9	4.9	4.5	4.5	5.0	4.9	5.2	4.8	5.5	5.5	4.6
Ruston, B162	5.0	5.0	4.0	4.0	5.1	4.8	4.8	4.8	4.9	5.0	4.8
Miami, 10341	6.7	6.7	6.0	6.0	6.8	6.6	7.0	6.9	7.0	6.5	6.7
Miami, 10342	5.9	5.9	6.2	5.5	6.2	6.2	6.4	6.0	6.0	6.0	6.2
Miami, 10343	6.3	6.2	5.5	5.0	6.6	6.3	6.8	6.6	6.3	6.0	6.2
Caribou, 10541	4.0	4.0	4.0	<4.0	4.4	4.4	4.4	4.0	4.3	4.0	4.4
Caribou, 10542	4.2	4.1	3.8	<4.0	4.4	4.6	4.8	4.2	4.0	4.0	4.4
Barnes, 10305	7.0	6.9	6.8	7.0	7.0	6.6	7.1	7.1	7.2	7.0	7.1
Barnes, 10306	7.1	7.1	6.8	7.0	6.8	6.6	7.1	7.0	7.0	7.0	6.9
Carrington, 10082	5.3	5.3	6.2	5.5	5.8	6.0	6.2	5.4	6.2	5.5	5.6
Carrington, 10083	4.9	4.9	5.5	5.0	5.8	5.6	5.6	5.0	5.3	5.0	4.8
Clinton, 10362	5.3	5.3	5.5	5.0	5.2	5.8	6.1	5.4	6.0	5.0	5.2
Clinton, 10363	4.7	4.6	5.0	4.0	4.8	4.6	5.5	4.8	4.8	4.0	4.0

In order to approximate the conditions under which the average person would use a soil-testing outfit, these tests were made by operators who had not had the experience of checking results obtained by the various methods with those obtained by an electrometric procedure. By repeated experience in comparing results obtained by any one of the test sets with results obtained by electrometric methods, an operator could probably improve his judgment in interpreting the various colors in terms of true pH values.

LIME REQUIREMENT

Lime-requirement values are sometimes obtained from definite chemical relationships, such as the quantity of limewater or other base required to neutralize the acid soils to a specified pH value. The Veitch method (*46*) is one of this kind. Some years ago this procedure had wide popularity, but now it is little used. The results obtained by the various chemical methods have contributed much information which aids in the practice of soil liming today. Several of the lime-requirement methods most used now are those related directly or indirectly to the pH value of untreated soil. The Simplex outfit is one in which pH is interpreted directly in terms of tons of lime required per acre. Some methods employ an indirect relationship to pH, such as the depth of redness of color imparted to a thiocyanate solution in contact with the soil. The recommendations as to liming given by Morgan (*29*) are based upon pH; the soil type, especially with reference to its texture and organic content; the calcium, magnesium, aluminum, and manganese shown by individual tests; and the soil pH preferences of the crop. A comparison of lime-requirement values by several methods is given in table 4.

TABLE 4.—*Lime requirement per acre for various soils indicated by different procedures as determined by analysts A and B*

Kind of soil and laboratory no.	Emerson		Rich or poor		Sudbury		Simplex		Veitch laboratory method
	A	B	A	B	A	B	A	B	
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Cecil, 9415	½	1	<2	1	1½	1½	1½	2	2
Cecil, 9416	1	2	<2	1	1½	1½	2	2	4
Ruston, B161	0	0	0	0	1½	2½	2	2	3
Ruston, B162	½	½	0	0	1	1½	2	2	3
Miami, 10341	0	0	2	0	½	½	0	½	1½
Miami, 10342	1	1	--------	1	½	½	1	1½	3
Miami, 10343	1	1	0	1	½	½	0	1½	5½
Caribou, 10541	3	3	4	4	1½	2½	2½	2½	5
Caribou, 10542	2	2½	3	3	2	2½	2	2½	5½
Barnes, 10305	0	0	0	0	0	0	0	0	0
Barnes. 10306	0	0	0	0	0	0	0	0	0
Carrington, 10082	½	½	<2	2	½	½	1	1½	2
Carrington, 10083	2	2	--------	3	--------	½	2	1½	3½
Clinton, 10362	1½	1	2	2	½	½	2	1½	1
Clinton, 10363	3	3	4	3	1	½	3	2	4

The poor agreement between results by certain lime-requirement methods is to be expected from the variation in principles upon which the estimates depend. If lime requirement represents the quantity of lime required to bring a soil to a particular pH value, then at least four factors influence the quantitative relationship of soil to base. These are: (1) The initial pH value, (2) the colloidal clay content, (3) the organic matter content, and (4) the exchangeable hydrogen content of the colloid, which is largely conditioned by its fundamental chemical composition. It is not to be expected that a sandy soil of pH 5 would have even approximately the same lime requirement as a heavy clay soil of this pH or that either of these should show values in close agreement with those of a soil of the same pH but rich in organic matter. The Hellige test kit takes these factors into account to some extent by dividing soils into two groups, "sandy soils" and "loams, clays, and mucks." The two groups vary in lime requirement at a particular pH.

EXTRACTION AND DETERMINATION OF PHOSPHORUS AND POTASSIUM

The chemical nature of the extracting solutions used in some of the test sets is not indicated. Intensity of the acidity of a solution in contact with soil has an important influence on the degree of solubility of some of the more easily soluble soil constituents. The pH values of each of the solutions prepared according to directions was determined by means of a glass electrode. These values are given in table 5.

TABLE 5.—*pH values of extracting solutions used for phosphorus and potassium by various methods*

Method	Phosphorus	Potassium	Method	Phosphorus	Potassium	Method	Phosphorus	Potassium
Simplex	3.27	3.27	Lac-hi-potash	-------	4.1	Hellige	1.10	1.10
LaMotte	1.9	4.08	Sudbury	.85	1.2	Truog	3.03	-------
Indiana	1.0	5.04	Emerson	1.15	1.25	Morgan	4.80	4.80
Hi-lo-fosfate	.85	-------						

The Simplex system employs a very weakly acidic extracting solution without a buffer. The results are relatively low as compared with those obtained by methods using much stronger acid solutions. The values for available constituents in most of the poorer soils are necessarily too low to be distinguished from one another when this weak extracting solution is used. This situation was noted by Morgan.[4] This kit should be of particular value for detecting excessive quantities of any constituent, such as may sometimes be found in garden soils or greenhouse pots which have been heavily fertilized.

Tests made according to the procedure outlined by Morgan (*29*) were included in the comparison of methods. This procedure employs an extracting solution of about pH 5, which is much less acid than the solutions used in most of the test sets. An extracting solution heavily buffered at this pH has frequently been found to be of particular value for diagnosing fertilizer needs in certain soils to which large quantities of phosphate have been added for previous crops but in which phosphate is no longer adequately available.

Figure 1 shows diagrammatically the available phosphate content of various soils as determined independently by two analysts by the several methods. Although the results by the various tests are conventionally expressed in different ways, all are placed in five groups in this and in subsequent figures. The designation VL indicates very low; L, low; M, medium; H, high; and VH, very high.

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[4] MORGAN, M. F. See footnote 2, p. 4.

The results for potash determinations are arranged in figure 2 in a manner similar to that used for phosphorus.

It is well known that the solubility of the relatively insoluble phosphates, such as tricalcium phosphate and iron and aluminum phosphates, are markedly influenced by the pH of an extracting solution and also by the presence of soluble salts. It is not surprising, therefore, that poor agreement is consistently found between results by certain of the procedures. The personal factor is greater in some cases than in others. Adjacent values in the diagram, such as low and very low, might easily be thrown into a single group by one observer and separated by another. Wider differences are probably the results of actual differences in the quantities of the phosphate dissolved in the two cases. An average of several determinations would probably eliminate most of the differences due to the personal factor,

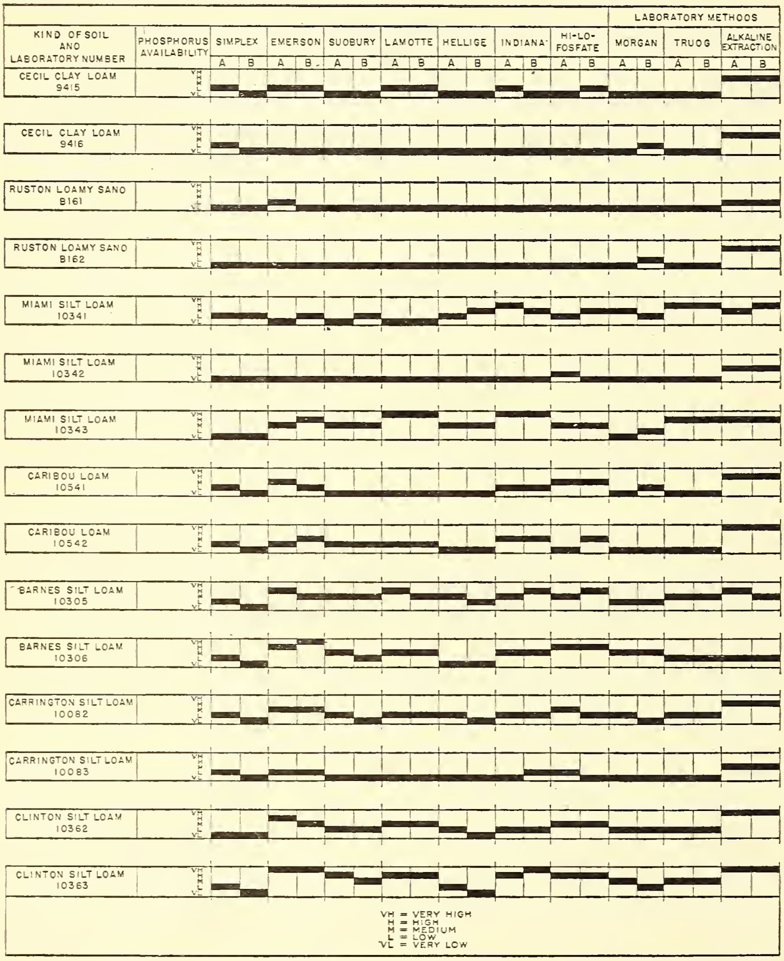

FIGURE 1.—Relative quantities of available phosphorus in various soils indicated by different procedures as determined by analysts A and B.

but such duplication was not thought desirable since this is not the usual practice when quick tests are used. Tests were repeated, however, when an operator had reason to think that any part of the operation was faulty or not comparable with the other determinations.

The alkaline carbonate extracting solution proposed by Whitney and Gardner (*47*) for calcareous soils was used on each of the soils included in this comparison, although its use on acid soils was not suggested by the authors. (See column at right in fig. 1.) The quantities of phosphorus extracted were usually much larger than the quantities extracted by any of the other solutions. The authors state that when soil phosphorus is determined according to the procedure described, a value of about 37 p. p. m. should be regarded as the dividing line between soils deficient in available phosphorus and those having sufficient. From this one statement the following arbitrary values, possibly not justified, were used in order to represent the data

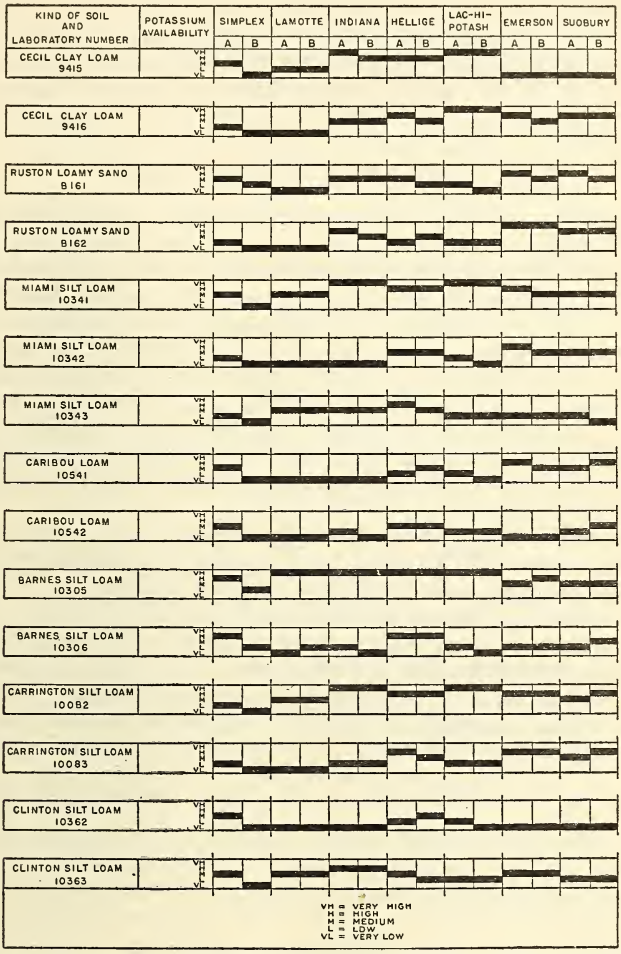

FIGURE 2.—Relative quantities of available potassium in various soils indicated by different procedures as determined by analysts A and B.

graphically for comparison with other methods: Less than 20 p. p. m.=very low, 20 to 30 p. p. m.=low, 30 to 50 p. p. m.=medium, 50 to 100 p. p. m.=high, and >100 p. p. m.=very high.

Small quantities of potassium are more difficult to detect accurately than are small quantities of phosphorus. Significant differences, however, are easily distinguishable. The potash requirement for different kinds of crops is particularly variable. Furthermore, the relation of quantity of potash extracted by a solvent to that taken up by a plant may vary considerably with the kind of soil used. Insufficient information is at hand to judge what value for potash should be considered adequate in various soils (*35*). However, with potash as with other constituents, when two or more different soils are considered, the differences in the values by the various tests may be pronounced.

AVAILABILITY OF SOIL NITROGEN

The availability of soil nitrogen has received much less attention from the chemical standpoint than that of either phosphorus or potassium. In the past, chemical methods for the study of the soil-nitrogen supply have been concerned for the most part with a determination of nitrates. Rapid chemical determinations have included tests for nitrates, ammonia nitrogen, and other tests related to the general availability of nitrogen. In some laboratories rapid approximate determinations of total carbon or organic matter are made as indirect indices of the nitrogen situation. Several sets provide tests for nitrates and ammonium nitrogen, and two provide a general nitrogen test. Several of these determinations are included in the comparative values given in figure 3.

Nitrates are for the most part easily extracted from soils by water, and for this reason only a supply adequate for plant needs over a short period is present in a soil at one time under humid soil conditions. A study of available nitrogen is often made by following the variations in nitrate content over a certain period of time. The quantity present at one time is seldom used as an index of nitrogen availability in general. The tests are well adapted for showing the presence of nitrates, but their semiquantitative aspects perhaps leave more to the individual judgment of the operator than do tests for other constituents.

RELATION OF CHEMICAL DATA TO FIELD FERTILIZER PRACTICE

No direct data are available regarding crop response to additions of fertilizers in areas immediately adjacent to the soils taken. However, information is available concerning each of the soil series and types. Various soil survey reports and State experiment station bulletins present the basis for some interesting comparisons. The information which follows was taken from such reports.

Hutton (*21*) of South Dakota reports the results of 20 years' experience with fertilizers on the Barnes silt loam soil of the college farm at Brookings. Addition of phosphorus alone gave greater increase in yield for all crops than any other treatment. The average increase over a period of 20 years was 32 percent above that of untreated soil. Nitrogen and potash used singly or together did not pay expenses of material and labor. A majority of the chemical tests made in this laboratory showed medium to high available phosphorus present and gave no consistent indication of a need for phosphorus fertilization.

The potash situation shown by field tests is well in accord with that shown by laboratory results.

The Carrington silt loam soil is not ordinarily treated with commercial fertilizers. However, field experiments conducted by the Iowa Agricultural Experiment Station (*39*) show that profitable increases in yield may be obtained from the use of rock phosphates or superphosphate. Experiments with potassium are fragmentary, and the results are not convincing. The fact that complete fertilizers give no greater yield than phosphate alone indicates that potash availability is satisfactory. The general consensus of laboratory results indicates that potassium in the surface soil may be adequate as is also the supply of nitrogen.

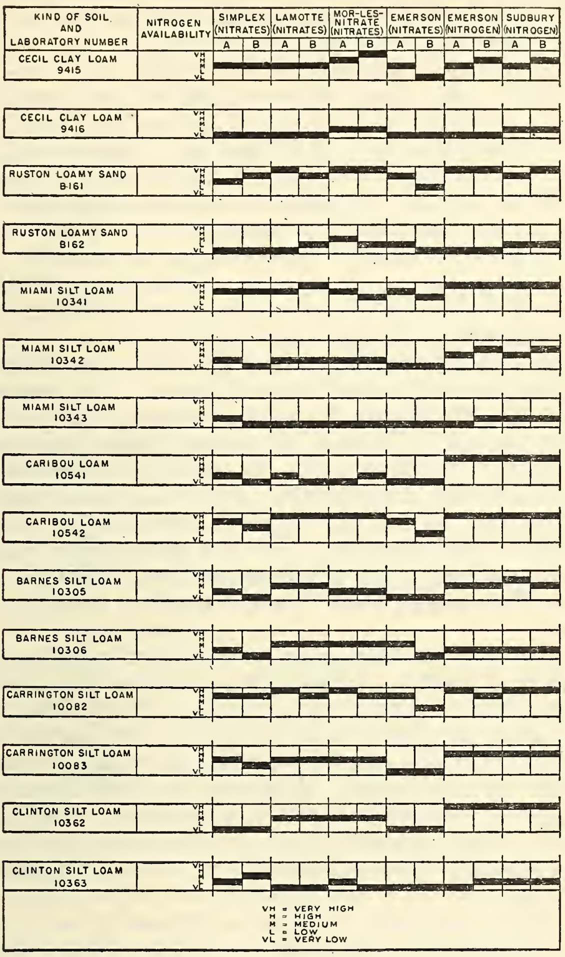

Figure 3.—Relative quantities of available nitrogen in various soils indicated by different procedures as determined by analysts A and B.

One of the older soil survey reports showed that the Clinton soils were satisfactorily productive when treated with the local supply of barnyard manure. Commercial fertilizers were not used. The laboratory results with these samples, when interpreted according to the directions of the makers of the test sets, indicate a need for potash but not for phosphorus.

The Indiana Agricultural Experiment Station recommends for silt loam soils of the State in general a commercial fertilizer of the approximate grade 2–12–6 (*48*). The high phosphorus of this formula is in accord with laboratory results for the two upper horizons of the Miami silt loam. Laboratory results for potash by the various methods are erratic but indicate a probable response from potassium fertilization.

The Cecil soils have long been fertilized for all major crops. The North Carolina Agricultural Experiment Station has published general advice regarding fertilization of these soils (*49*). The grade suggested is 4–10–4, with applications of 200 to 800 pounds per acre, depending on the kind of crop grown. Laboratory tests indicate particularly a need for phosphorus fertilization. Results with potash are highly erratic and far from conclusive. The station also reports that in North Carolina the Ruston sandy loam soils respond most profitably to an application of about 900 pounds per acre of a 7–5–4 or 8–6–5 fertilizer. Results for crops from Georgia, near where the Ruston sample was taken, are not available. Laboratory results indicate that there is a definite need for phosphorus in the virgin soil and that a favorable response to potash is probable.

The Maine Agricultural Experiment Station has made extensive fertilization studies on the Caribou soil series. One ton per acre of a 4–8–10 fertilizer is frequently used for potatoes. The untreated soils often produce potatoes having definite physiological symptoms of potash deficiency. Fertilizers with potash up to 6 percent are usually considered a profitable investment. The bleached sandy horizon of this soil is severely depleted of most of the nutrients. The phosphate tests in particular indicate this. The B horizon below contains more of the total constituents, but the apparent availability is not materially greater. Presumably these two horizons are mixed in the process of cultivation.

Fertilizer practices on the various soil series tested are given here in order that they may to some extent guide the prospective user of quick chemical tests. The results given in this publication are not presented to prove or disprove the merits of the particular tests, or to show definitely that a soil will or will not respond to additions of a particular fertilizer element. Although no definite statements can be made regarding the general correlation of quick chemical tests with crop responses, it is thought that the results presented here may help a prospective user to decide whether or not it would probably be to his advantage to purchase one or more of these outfits or have such tests made. The tests have been considered by many to be better than guesses, and within particular localities they have been reported to be of marked diagnostic value. None goes so far as to claim great reliability for any one test for all crops on all kinds of soils. Many feel, however, that current widespread interest in rapid chemical tests is justified by the results and that gradually sufficient information may become available so that a test properly adapted to the soil and crop to be grown may be selected.

OTHER SOIL CONSTITUENTS

In addition to the soil constituents just discussed, other elements play an important part in plant nutrition. Some of these may be determined by certain of the quick-test outfits, but owing to their limited use on these elements comparisons are not included here. Less is known regarding the normal plant requirements for such elements as calcium, magnesium, and manganese than for constituents ordinarily considered as fertilizers. Still less is known regarding the requirements for some of the rarer elements, such as copper and zinc.

GENERAL RELATIONS

It may occur to some readers that the results obtained in this laboratory with various quick-test procedures give an impression of their practical worth more gloomy than is justified by the experience of several State laboratories. Attention is again called to the fact that in these institutions the tests are made and interpreted by agriculturists who have had broad experience with the groups of soils being tested. Furthermore, they have definite knowledge concerning the nutritional requirements of the crops normally grown and of the adaptation of various crops to particular soil types as well as knowledge concerning the response of these crops to fertilizer applications under different conditions. With this background of experience, quick chemical tests are often found to be a great aid in making interpretations helpful for practical purposes. There is no doubt about their value to farmers in such States as Wisconsin, Maryland, Indiana, Virginia, and others where they are extensively used by trained workers. However, if one of these laboratories should receive a soil sample from some distant locality where the soil is vastly different and different kinds of crops are grown, it is probable that the advice given on the basis of chemical data alone would be much less definite and its economic worth much less dependable than advice in a particular State by its own experiment station.

In the field of chemical soil tests for determining the mineral requirements of plants much remains to be done. It is necessary to consider not only the concentration of a particular element which may be available for the use of a plant but the relation of each element to all others. The coincidence of factors has been emphasized by Spurway [5] and by Jarvis (*22*) and doubtless deserves further attention. This Bureau hopes ultimately to obtain fairly definite information regarding the coincidence of factors and the fertility level in a group of the more important soils throughout the United States. From the data presented from various sources it is hoped that chemical tests may be so adapted to soil character that they will establish with greater definiteness the needs of various plants. It is not expected that any set of tests of this kind will ever be close to 100 percent in accuracy, but it can well be expected that they may be developed to a point where they rate well among tests which are related to biological factors.

SUMMARY

A brief review is given of the development of rapid chemical tests for the evaluation of the state of fertility of soils and their probable response to fertilizer applications.

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[5] SPURWAY, C. H. SOME CONSIDERATIONS CONCERNING THE PRACTICAL INTERPRETATIONS OF SOIL TEST RESULTS. Amer. Soc. Agron. Proc. Ann. Meeting 1: 102-106. 1935. [Mimeographed.]

Comparable tests were made upon a group of widely diversified soils with several of the widely used commercial soil-testing sets. The soils used were virgin samples of Barnes silt loam, Carrington silt loam, Clinton silt loam, Miami silt loam, Cecil clay loam, Ruston loamy sand, and Caribou loam. The tests, made independently by two operators, were for available phosphorus and potassium and for acidity, lime requirement, and nitrates. The sets used were the Simplex, Emerson, LaMotte, Sudbury, and Hellige, and the test sets made by the Urbana Laboratories and that made and used by the Indiana Agricultural Experiment Station. Some of the laboratory tests not used commercially were included.

The results obtained by two observers with the same set on a particular soil were in fairly good agreement, but results by different methods on the same soil were in much poorer agreement.

The data are given only to show the general trend of results that may be expected when different test sets are used on various soils. No information is at hand regarding actual crop response on these soils when treated to correct the indicated deficiencies.

In many State experiment stations chemical tests have been found a valuable aid for the diagnosis of soil needs when interpreted by trained agronomists in possession of information regarding the response of various crops grown on different local soils after application of fertilizers. The use of any one of these tests is neither recommended nor condemned. They are thought to be of particular value under certain circumstances, but the scope of their usefulness is not yet clearly defined.

Preliminary investigations only are discussed in this publication. It is realized that further investigations must be made, especially of diversified soils growing crops in response to various fertilizer treatments.

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